Sun – Our Fascinating Star

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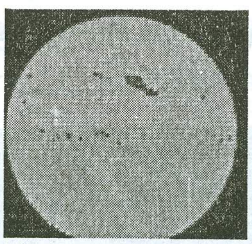
Introduction

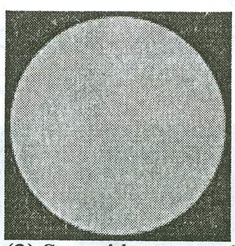
Sun, a star of spectral type G2 is the main source of energy to the Earth. Being close to the Earth, Sun produces a resolvable disk of great detail, which is not possible for other stars. Stars are classified based on their surface temperature. O B A F G K M are the types of stars, the hot stars O having surface temperature ranging from 25000-60000 degree Kelvin, whereas the cool M type stars have 3000 degree. Depending on the small temperature scale variations, sub classifications 0, 1, 2,..3,....9 are made in each type. The temperature of the stars determines the physical and chemical conditions prevailing in the atmospheres of the stars. In the spectrum of O type stars, the singly ionized helium lines are strong, and in the late type M stars the molecular lines appear stronger. Sun, being a G type star, the singly ionized Ca K and H lines are found to be stronger in its atmosphere (Saha 1921). Sun provides the illumination to the earth, warms us, nurtures our crops, and influences our weather. It is located at a distance of 20,000 light years from the centre of our galaxy 'Milky Way'. However, it is only an average star among 100 billions stars of our galaxy. Likewise 100 billion galaxies are known to exist in our Universe. When seen from the distance of our neighbouring star 'Alpha Centauri', sun would be just a point source in the sky. However, from our vantage point, it is possible for us to see how this jewel of star is made of and the interesting activities that take place in its atmosphere. More interestingly it is now possible for us to even probe what is going on inside our star through the study of helioseismology.

Interior of the Sun

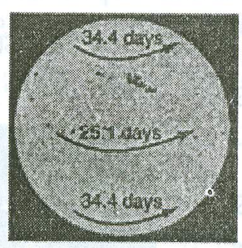
Sun has a size or diameter of approximately 1,400,000 km. Volume wise, it can fill in one million earths. We will make our imaginary travel from the centre of the sun to the surface from where the light starts pouring out in all directions in the form of electromagnetic radiation. The internal metabolism of the sun makes us to understand that sun is not just a passive lump of gas. We will come across the internal structure of the sun as a hard core where the energy generation takes place. The high density, pressure and temperature prevails in the core of the sun, triggers the thermo nuclear reaction to take place. The hydrogen burning core occupies nearly one third of solar radius. It can outshine the surface of the sun by more than 10^{13} times. The core is surrounded by a misty radiative zone through which the energy slowly diffuses to the surface. The radiative zone is slightly more than one third of the solar radius and it acts like an insulating layer. But for this interesting layer, the energy generated might have been dissolved into the space in no time. It is highly fascinating to note that though the light what we see takes 8 minutes and 20 seconds to reach the earth's surface, it might have started its journey from the core of the sun many millions of



(1) Sun with sunspots



(2) Sun without sun spots



(3) Differential rotation of the sun

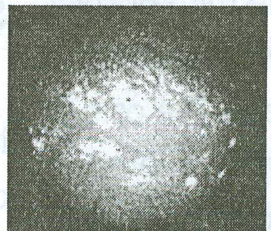
years earlier to reach the surface. Sun is still at its young age of 4.25 billion years. The radiative zone is enveloped by an interesting convection zone of slightly less than one third of the solar radius. The convective zone works as a powerful generator. This dynamo action makes the sun as an interesting object of study. It produces solar activity, and also poses few challenging questions that are yet to be resolved.

Solar Atmosphere

As we come out of the interior and look into the surface and the atmosphere of the sun, we can observe various interesting magnetic features that are called active regions (Zirin 1988). Solar atmosphere is divided into three zones. Since electromagnetic radiations come in the form of photons from the surface of the sun, the region is called 'photosphere'. The photosphere extends up to 100 km as sun does not have a solid surface like that of the earth. The white light picture of the sun shows the surface or photosphere of the sun. The red colour is due to the filter used while taking the pictures. The large sunspot that we see in Figure 1 may be 30 times the size of the earth. Sun has a differential rotation, the equator rotating faster than the poles. The solar equatorial region rotates at the rate of once in 25.1 days compared to the 34.4 days rotation in the pole regions (Figure 3).

This differential rotation coupled with the convection inside the sun is thought to be responsible for the Faraday action to form sunspots (Bray and Loughead 1964). Sunspots appear darker since the temperature prevailing in these localized regions is low compared to their surroundings. Strangely it looks like ice in an oven. The strong magnetic field that is prevailing in the sunspot is shielding it from the hot surroundings and also makes it cooler.

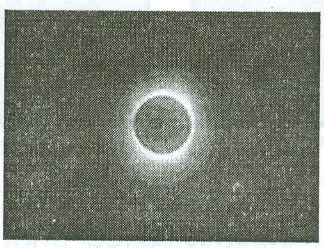
(4) H alpha image of the sun



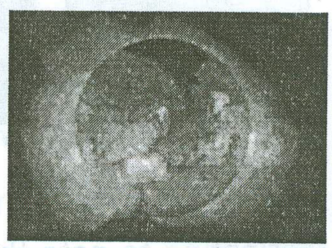
(5) Ca K image of the sun

Chromosphere is the atmosphere of the sun above the photosphere and can be observed by taking the picture of the sun in H alpha and Ca K lines. Figures 4 and 5 show the dark and bright choromospheric magnetic features of the sun. The H alpha and Ca K lines are highly sensitive to magnetic field and temperature variations. Some times the magnetic fields in these regions become highly unstable resulting in solar storms or solar flares. The chromosphere extends up to 2500 km from the surface of the sun. The chromospheric features also keep changing with time. The atmosphere above the chromsophere is the tenuous corona which will be visible during total solar eclipse.

Moon is 400 times smaller than the sun, but at the same time is put up 400 times closer to the earth compared to the sun. It is a very happy coincidence. Due to this fact, when the moon comes exactly in between the sun and the earth, total eclipse of the sun occurs. At the time of the total solar eclipse, both the inner atmospheres of the sun, photosphere and chromosphere will be totally covered ; the outer most atmosphere of the sun, corona alone will be visible. Figure 6 shows the total eclipse ob-



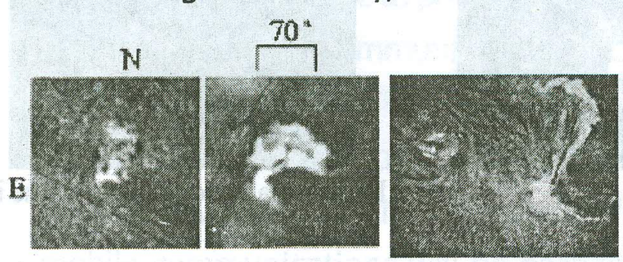
(6) Total solar eclipse observed at China on 22.7.2009



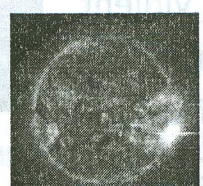
(7) Solar corona showing magnetic features

served in China on 22nd July 2009 by our Indian team. Since this part of the atmosphere is visible like a 'crown' to the sun, the name corona has come from Latin. Incidentally solar corona extends beyond the earth, and earth is immersed in the corona. Figure 7 shows the solar corona photographed in X-ray from the space. The bright loops like features are magnetically active regions in the corona. The dark region observed in Figure 7 is the 'coronal hole' from where solar wind originates. The important scientific aspect of the solar corona is its high temperature ranging from 1-5 million degrees. Thus X-rays are emitted from hot corona. Since X-rays do not reach the earth's surface, coronal pictures are taken at any time from a space lab. The space craft should have a pay load of X-ray spectrometer to study the coronal activity.

Though to a certain extent, we could understand the formation and rhythmic cycle of the magnetic activity, still a lot more has to be understood from the solar activity and associated physical processes. First question that constantly triggers our mind is how the outer atmosphere of the sun is heated to million degrees (Gibson 1973). Since heat can't run from cooler to upper regions, something other than heat and light from the surface may be responsible for the high temperature in the outer atmosphere. The quest for answer still goes on. The next question that constantly strikes the mind is the continuous flow of solar wind at speeds as high as 1000 km/s. This gusty wind produces auroras and geomagnetic storms, and these events constantly shake the earth's magnetic field. Still we don't know how the solar wind is accelerated to such high speeds. Another interesting event that occurs in the solar atmosphere is the solar flare (Carrington 1859, Hodgson 1859). Figures 8 and 9 show the flares observed in chromosphere and corona.



(8) Solar flares observed in H alpha


(9) Flare in X-ray

Solar flares are associated with the magnetic activity and produce deadly ultraviolet light, X-rays and solar cosmic rays. A medium sized flare can release the energy equivalent of a billion megatons of TNT in a few minutes. Solar astronomers are trying to understand the energy storing mechanism involved in such events. It is also interesting to find out how this energy is suddenly released. The next curious phenomenon is the mass ejections (CME) that occur almost every day from the outer solar atmosphere (Figure 10). We still have fuzzy ideas on how such a huge amount of mass made up of plasma is expelled suddenly from the sun. As these violent phenomena shows the sun's dangerous face to us, it becomes important to study and probe them completely in order to avert some of the huge damages that we may come across during the course of such events. The aspect of study is called '**space weather**' and it forms the interesting topic of the present decade.

Carrington event : A servere solar storm that can damage the modern aminities of the present world, like the satelite distrutions, damage to power grids and so on.

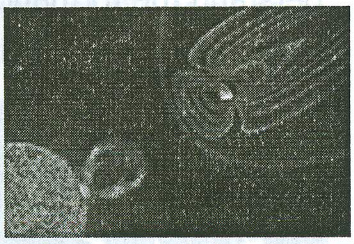
Coronal Mass Ejection (CME) : A huge volume of eletrified gas amounting to billions of tons of material in the form of electric charges will be expelled from the sun spontoneously. It may be accompanied by a solarflare / storm or can happen without a storm.

Frequent occurrence of such energetic events can occur during the period of solar maximum when the spot activity peaks up. Next solar maximum is expected during 2012-13

Space Weather – Geo-effects of Solar Activity

Space weather refers to the violent transfer of energy and particles from the sun to the earth. Huge volumes of electrified plasma having mass millions to billions of tons will be thrown by the Sun in any or every direction. The phenomena happen almost every day, whereas the occurrence of these storms will be more during the period of solar maximum. The radiation takes slightly more than 8 minutes to reach the earth whereas the charged particles may arrive in 3-4 days. In the absence of our atmosphere, earth will be roasted and fried due to these powerful storms, as they travel with tremendous amount of thermal and kinetic energy. Fortunately earth's magnetic field provides protection through its invisible layer. Though it is relatively weak, the extrapolation of this magnetic field around the volume of the earth provides a bubble shaped shied (Figure 11)

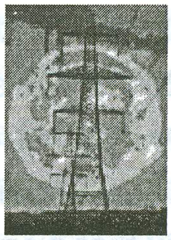
10. CME



11. Earth's magnetoshphere in blue is facing the CME from the sun

deflecting the charged particles. Thus cosmic, solar electrons and ions are driven away from the most heavily inhabited areas of the earth's surface in spite of the influx of particles toward the magnetic poles getting enhanced. The topology of the magnetic field is also such that high-energy particles can be trapped in belts circling the globe, with major consequences for the orbiting spacecraft. When a sudden transient event like magnetic storm from the sun arrive the regions of the Earth's magnetic field, the protection some times breaks down depending on the power of the storm and life on the ground gets affected. These magnetic storms may shake the earth's magnetic field as they consist of mass made up of mostly charged particles that produce huge amounts of power amounting to million mega watts. Incidentally that amount of power may be sufficient to the entire India for a week or so.

Thus a powerful earth directed CME due to bad space weather could induce electricity in large overloading electrical systems and cause massive damage to power grids. Long distance telephone communications through cable distribution and GPS operations will be disturbed. Satellite operations, TV and Internet transmissions through satellites and mobile communications will be partially or totally halted as a powerful storm can permanently damage the spacecrafts. The astronauts on board and the high altitude air travels are prone for attack if these events are earth directed. As we are put up close to the earth's equator, chances of such happenings are rare in our regions. Nevertheless, a powerful event may even cause damage to the power grids in the low latitude belts (Figure 12). However, when the solar


12. Impact on power grid


13. Aurora

particles try to penetrate the earth's atmosphere their energy will be dissipated. Their interaction with our atmospheric particles produces colourful skies known as 'auroras' that are visible in high latitude belts (Figure 13).

The present scenario for tackling bad space weather

It has now been realized how to safeguard the power grids by configuring it with the direction and speed of the electric currents induced due to space weather. Also the satellites are equipped with devices to safeguard them from the current surges due to bad space weather. The stage is set for warning the astronauts on space to take protective measures. The study of space weather has made it possible for us to avert majority of the damages that can be caused due to solar storms. We are slowly approaching towards the next solar maximum that is expected during 2012-2013. Nonetheless, the sunspot activity during this 24th cycle has not picked up rapidly. Unusually the spotless days during this cycle has exceeded 800. Sunspots started appearing slowly from 2009 onwards and we could find hardly a spot group or two during 2010. The slow pick up of the solar activity may not give rise to powerful storms or CMEs contrary to the media reports which say that a severe killer storm may arrive from the sun during 2012.

Fortunately such a type of 'carrington event' will be rare to happen, may be once in half a millennium. Half a dozen strong X type flares are reported only during September-October 2011, some of them associated with CME after a long gap of 5 years. The dull solar activity during this cycle looks to be peculiar. The solar activity is a common one and occurs periodically. Specifically there is not going to be a massive life killing solar flare or CME in 2012-13.

The present stage is set for getting continuous solar data from both space and ground with high time cadence thus making the predictions of such events easier. Once these events are predicted, the quick communication to the technological systems in the earth will avert the damages due to solar events. Therefore, the panic situation need not arise at all. It is only a hype that the earth is going to be fried and toasted during the next solar maximum, making the life on the earth coming to a sudden halt. Rather we can happily welcome the next solar maximum as life on the earth will continue to go smoothly and that too with a better understanding of the technology and modern science.

Acknowledgements

The photographs taken from the NASA web site are purely used for educating the students and public and not for any research purposes. We sincerely thank and acknowledge **NASA** for the photographs.

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